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Atlas of Probabilities of Surface Temperature Extremes

Part II—Southern Hemisphere

PAUL TATTELMAN
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27 December 1976

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Chief Scientist

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The method for calculating warm and cold temperature extremes, described in Part I for the Northern Hemisphere, is used in this report (Part II) for an analogous presentation in the Southern Hemisphere. A bias in the estimates of cold temperature extremes for the Southern Hemisphere is discussed and evaluated in this report, resulting in development of a new set of regression equations to depict cold temperature extremes. The resulting Southern Hemisphere maps of the 1-, 5-, and 10-percent warm temperatures, next page

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20. Abstract (continued)

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and the 1-, 5-, 10-, and 20-percent cold temperatures for the warmest and coldest months, respectively, are presented. Parts I and II of this report together provide a global representation of warm and cold surface temperature extremes for use in systems design and operation.

Preface

The authors wish to acknowledge the timely help received from the USAF Environmental Technical Applications Center, particularly in supplying last-minute data on hourly temperatures in the Southern Hemisphere. We also express our appreciation to Ms. Melinda Zouvelos for her efforts in preparing the data and plotting the percentile maps for analysis. Her performance in completing numerous calculations and otherwise processing the data was exceptional. Finally, we thank Mrs. Helen Connell, our typist, for a job well done.

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1. INTRODUCTION

Military Standard Climatic Extremes for Military Equipment, MIL-STD-210B, established uniform climatic design criteria for military materiel intended for worldwide use (excluding the area south of 60°S). However, the Air Force Geophysics Laboratory (AFGL) recognized the limitations of MIL-STD-210B in meeting requirements for climatic information for design of systems which are not intended for worldwide use. Accordingly, plans were formulated to prepare world atlases of climatic contour maps to enable the designer to ascertain climatic extremes for any particular geographic area of concern.

This report, Part II, provides percentile maps of surface temperature for the land areas of the Southern Hemisphere north of 60°S. Part I of this report, dated April 1976,[1] provides analogous information for the Northern Hemisphere. The percentiles conform to the basic risk philosophy used to determine operational design values for MIL-STD-210B; that is, equipment should operate except during extremes that are exceeded for a small percentage of time during the worst month of the year in a given geographic area of interest.

(Received for Publication 23 December 1976)

1. Tattelman, P., and Kantor, A.J. (1976) Atlas of Probabilities of Surface Temperature Extremes: Part I - Northern Hemisphere, AFGL-TR-76-0084.

In MIL-STD-210B, the extreme exceeded 1 percent of the time during the worst month (the 1-percent temperature) is used as the design criterion for all but two climatic elements. One of these is the surface cold temperature for which the 20-percent extreme is used.[2] For surface warm temperatures, MIL-STD-210B prescribes that equipment should operate with a 1-percent risk of inoperability during the worst month of the year.

Most previous studies of temperature for design (for example, Tattelman et al,[3] Billions,[4] Salmela and Sissenwine,[5] Gringorten and Sissenwine,[6] Tattelman,[7] Gringorten,[8] Williams,[9] and Bennett et al,[10]) some of which were used to determine the warm and cold temperature criteria for MIL-STD-210B, directed attention only to the most severe locations. This study provides extremes for the land surface of the Southern Hemisphere north of 60°S. For cold temperature, maps of temperatures equalled or colder, 1-, 5-, 10- and 20-percent of the time during the coldest month (up to +10C) are presented. For warm temperature, maps of temperatures equalled or exceeded during 1-, 5-, and 10-percent of the time during the warmest month (down to +10 C) are presented.

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2. Dept. of Defense (1973) Military Standard Climatic Extremes for Military Equipment, MIL-STD-210B, 15 Dec. 1973, Standardization Division, Office of the Assistant Secretary of Defense (I&L), Washington, D.C. 20305.

3. Tattelman, P.I., Sissenwine, N., and Lenhard, R.W., Jr. (1969) World Frequency of High Temperature, AFCRL-69-0348.

4. Billions, N.S. (1972) Frequencies and Durations of Surface Temperatures in Hot Dry Climatic Category Areas, U.S. Army Missile Command, Redstone Arsenal, Tech. Report RR-72-13.

5. Salmela, H.A., and Sissenwine, N. (1970) Estimated Frequency of Cold Temperatures Over the Northern Hemisphere, AFCRL-70-0158.

6. Gringorten, I.I., and Sissenwine, N. (1970) Unusual Extremes and Diurnal Cycles of Desert Heat Loads, AFCRL-70-0332.

7. Tattelman, P. (1968) Duration of Cold Temperature Over North America, AFCRL-68-0232.

8. Gringorten, I.I. (1970) Duration and Unusual Extremes of Cold, AFCRL-70-0381.

9. Williams, L. (1972) A Contribution to the Philosophy of Climatic Design Limits for Army Materiel: Extreme Hot-Desert Conditions, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Va., Tech. Report ETL-TR-72-5.

10. Bennett, I.V., Pratt, R.L., and Frodigh, R.J. (1964) World Maps of High Dry-Bulb and Wet-Bulb Temperatures, U.S. Army Natick Laboratories, Natick, Massachusetts, Tech. Report ES-11.

2. METHODOLOGY

The ideal method to determine the frequency distribution of temperature would be to obtain actual hourly temperatures for a long period. These data are readily available for a large number of stations in North America, but on a world-wide basis, an insufficient number of stations are available with complete, long term records (at least 10 years) to permit an accurate analysis. To overcome this difficulty, a technique was developed[1] for estimating the frequency distribution of warm and cold temperatures from readily available climatic data. It was determined that warm (and cold) temperatures corresponding to small probabilities of exceedance are found where the monthly mean temperatures are warmest (and coldest) and the mean daily range is greatest. Indices of these values are expressed by:

$$I_w = \overline{T} + (\overline{T}_x - \overline{T}_n) \tag{1}$$

and

$$I_c = \overline{T} - (\overline{T}_x - \overline{T}_n) \tag{2}$$

where I_w is the warm temperature index, I_c is the cold temperature index, $\overline{T}$ is the mean, $\overline{T}_x$ is the mean daily maximum, and $\overline{T}_n$ is the mean daily minimum for the warmest (coldest) month.

Regression equations of the 1-, 5-, and 10-percent warm temperatures, and the 1-, 5-, 10-, and 20-percent cold temperatures at 43 stations on the indices I_w and I_c, respectively, are provided in Part I of this report. These yielded linear correlations of 0.97 for $T_{1\%}$, and 0.98 for both $T_{5\%}$ and $T_{10\%}$ warm temperatures, and 0.98 for $T_{1\%}$, 0.99 for both $T_{5\%}$ and $T_{10\%}$, and 0.995 for $T_{20\%}$ cold temperatures. The corresponding scatter diagrams and least square regression lines are shown in Figures 1 and 2.

2.1 Cold Temperature Extremes

It was noted in Part I that there was a bias toward estimating too cold a temperature at warmer locations. This is evident from the scatter diagrams and regression lines for the cold temperature extremes in Figure 2. This bias appears to be confined to areas with 1-percent cold temperature extremes down to about -10 C (14 F). One-percent cold temperature extremes this warm are found primarily south of 30°N and in midlatitude locations with a strong maritime influence.

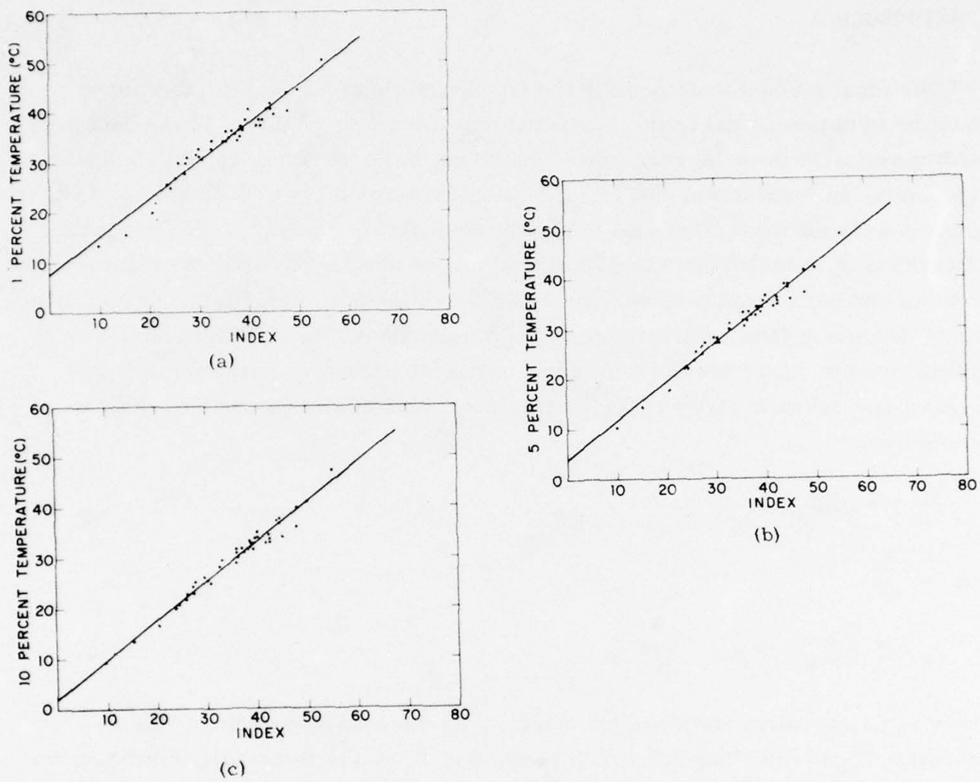

Figure 1. Percent Warm Temperature vs Index: (a) 1 percent; (b) 5 percent; (c) 10 percent

This bias is limited to a relatively small percentage of the total land area of the Northern Hemisphere where extremes of cold ordinarily are not of concern in design.

In the Southern Hemisphere (the Antarctic excluded), extremes of cold below -10 C are quite rare since most of the land area is at low latitudes and/or under strong maritime influence. Consequently, the cold temperature regression curves for the Northern Hemisphere result in a bias toward estimating colder temperatures for virtually all of the Southern Hemisphere. In fact, the predicted 1-percent temperatures for the coldest month were colder than the monthly observed extremes at many locations.

In an effort to eliminate this bias, hourly temperature data for the coldest months at 20 Southern Hemisphere stations were analyzed to better describe the true temperature distribution in the Southern Hemisphere. Unfortunately, much

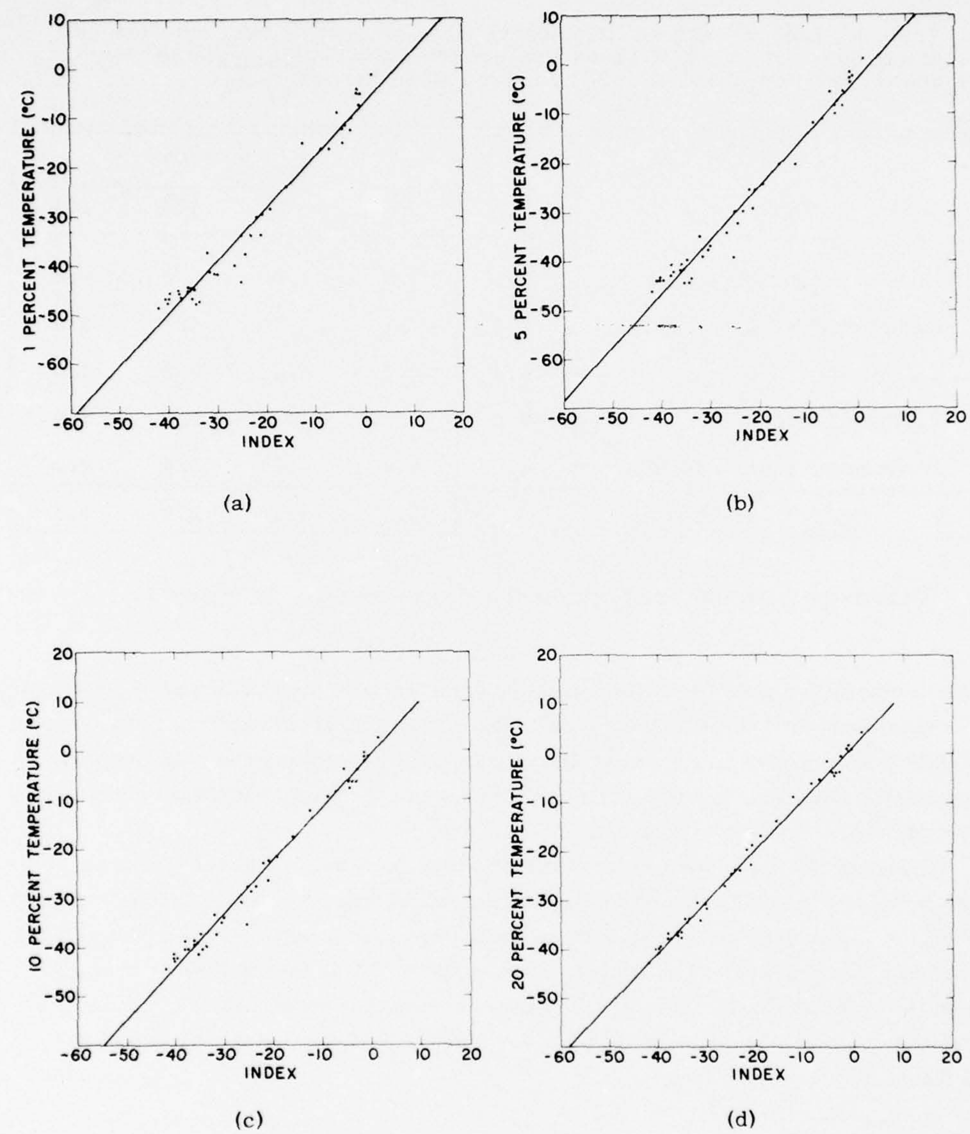

Figure 2. Percent Cold Temperature vs Index for the Northern Hemisphere: (a) 1 percent; (b) 5 percent; (c) 10 percent; (d) 20 percent

of the available Southern Hemisphere temperature records are incomplete. Temperatures at most locations are available only for the daylight hours and/or only on a three- or six-hourly basis. Only five stations had hourly records sufficiently complete to be of use. These are listed in Table 1 along with their respective

Table 1. List of Southern Hemisphere Stations Showing the Cold Temperature Index (I_c), the Difference Between the Actual and Calculated* Percentile Temperatures ($T_a - T_c$), and the Mean Bias ($\overline{T_a - T_c}$)

Station	I_c	$T_a - T_c$ (°C) 1%	5%	10%	20%
Buenos Aires, Argentine	6.1	3.0	1.6	1.0	0.0
Christchurch, New Zealand	-2.8	7.7	5.7	4.9	4.3
La Forado, Chile	4.4	6.1	4.5	3.3	1.7
La Paz, Bolivia	-3.2	4.6	4.2	3.1	2.4
Wellington, New Zealand	3.9	5.9	4.3	3.4	2.3
Mean Bias		5.5	4.1	3.1	2.1

*Calculated from the equations for the regression lines in Figure 2.

cold temperature indices, differences between the actual and calculated percentile temperatures, and the resulting mean bias. It is significant that the actual percentile temperatures are warmer than those calculated using the cold temperature regression equations for every station and percentile (except for the Buenos Aires 20-percentiles, which are equal).

Since five Southern Hemisphere stations are too few for a new regression analysis, it was decided to develop a second set of regression equations which include Northern Hemisphere stations with climatic regimes similar to those found in the Southern Hemisphere. The analysis was based on 14 Northern Hemisphere locations for which temperature distributions were readily available,[11, 12] plus five stations from the Southern Hemisphere. Stations and pertinent data are shown in Table 2.

11. Arctic Meteorology Research Group, McGill Univ., Montreal (1960) Temperature and Wind Frequency Tables for North America and Greenland, Vol. 1, Prepared for Hq Quartermaster Res. & Eng. Command, U.S. Army, Natick, MA. under contract No. DA19-129-QM-1447, O. I. No. 9177.

12. Arctic Meteorology Research Group, McGill Univ., Montreal (1960) Temperature and Wind Frequency Tables for Eurasia, Vol I, Prepared for Hq Quartermaster Res. & Eng. Command, U.S. Army, Natick, MA. under contract No. DA19-129-QM-1447, O.I. No. 9177.

Table 2. List of Stations Showing 1-, 5-, 10-, and 20-percent Cold Temperatures (°C) During the Coldest Month; also, mean ($\overline{T}$), mean daily range ($\overline{T}_x$ - $\overline{T}_n$), and Index $\overline{T}$ - ($\overline{T}_x$ - $\overline{T}_n$)

Station/Country	Alt (m)	Lat/Long	$\overline{T}$	$\overline{T}_x$-$\overline{T}_n$	Index (I)	$T_{1\%}$	$T_{5\%}$	$T_{10\%}$	$T_{20\%}$
Dharan/Arabia	22	26N/50E	16.4	8.3	8.1	5.9	8.9	10.4	12.0
Buenos Aires/Argentina	27	35S/58W	11.4	5.3	6.1	2.8	5.1	6.8	8.3
La Paz/Bolivia	3658	17S/68W	6.2	9.4	-3.2	-5.6	-2.3	-1.1	0.9
La Forado/Chili	138	30S/71W	10.7	6.3	4.4	4.0	6.2	7.3	8.2
Bentwaters AFS/England	29	52N/01E	3.6	4.5	-0.9	-5.0	-2.2	-1.1	0.6
Burtonwood AB/England	27	53N/03E	3.6	4.9	-1.3	-5.0	-2.8	-1.1	0.6
London/England	25	51N/00E	4.2	5.6	-1.4	-4.4	-1.7	-0.6	1.1
Mildenhall AFS/England	10	52N/00E	3.6	5.0	-1.4	-7.2	-3.3	-1.7	0.6
Christchurch/New Zealand	10	44S/173E	5.9	8.7	-2.8	-2.1	-0.4	1.1	3.2
Wellington/New Zealand	126	41S/175E	9.3	5.4	3.9	3.3	5.4	6.8	8.3
Brownsville/USA	6	26N/97W	15.3	10.6	4.7	0.6	5.9	8.3	11.7
Houston/USA	12	30N/95W	11.7	10.0	1.7	-3.1	1.6	4.3	7.3
Jacksonville/USA	9	30N/82W	13.3	10.0	3.3	-0.9	2.2	4.4	7.2
Medford/USA	396	42N/123W	2.6	8.3	-5.7	-10.6	-5.3	-3.3	-1.2
Miami/USA	8	26N/80W	19.6	9.4	10.2	6.0	10.0	12.4	15.6
New Orleans/USA	2	30N/90W	11.6	10.4	1.2	0.7	3.8	5.7	8.2
San Diego/USA	9	33N/117W	12.8	8.9	3.9	3.6	5.7	7.1	8.8
San Francisco/USA	5	38N/122W	9.1	7.8	1.3	-1.1	1.1	2.5	4.2
Tatoosh Is/USA	31	48N/125W	5.5	3.3	2.2	-6.5	-2.7	-0.9	1.3

From the information in Table 2, the following regression lines for the 1-, 5-, 10-, and 20-percent cold temperatures were derived by the method of least squares:

$$T_{1\%} = 1.036\ I_c - 3.165 \tag{3}$$

$$T_{5\%} = 1.019\ I_c + 0.012 \tag{4}$$

$$T_{10\%} = 1.052\ I_c + 1.643 \tag{5}$$

$$T_{20\%} = 1.074\ I_c + 3.688 \tag{6}$$

These equations were used to determine the cold percentile temperatures for the Southern Hemisphere. Linear correlations are 0.88 for $T_{1\%}$, 0.92 for $T_{5\%}$ and $T_{10\%}$, and 0.91 for $T_{20\%}$. The standard errors of estimate are 2.22, 1.75, 1.75, and 1.93 C, respectively. Scatter diagrams and least square regression lines plus the corresponding lines for the Northern Hemisphere (from Figure 2) are shown in Figure 3.

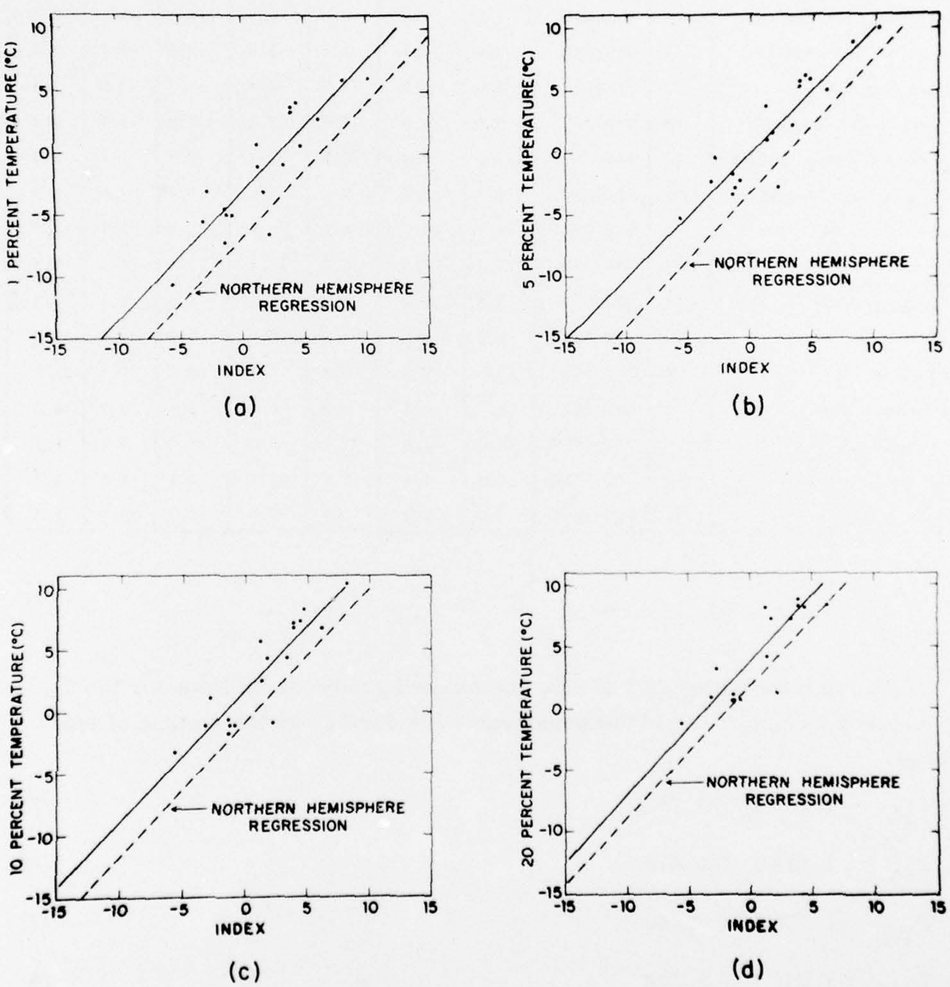

Figure 3. Percent Cold Temperature vs Index for the Southern Hemisphere: (a) 1 percent; (b) 5 percent; (c) 10 percent; (d) 20 percent

2.2 Warm Temperature Extremes

A bias toward estimating too warm a temperature at the cooler end of the warm temperature regression lines can be seen in Figure 1 for the warm extremes. Temperatures estimated by the regression lines, particularly the 1- and 5-percent curves, are warmer than the actual temperatures for the three coldest locations. This bias, however, is confined to those locations with 1-percent warm temperatures of about 20 C (68 F) or less. One-percent warm temperature extremes this cool are limited primarily to latitudes north of 60°N in the Northern Hemisphere, where warm temperature extremes are not significant for design purposes. Since such extremes are essentially non-existent in the Southern Hemisphere, the original regression analyses for the warm extremes are used herein. The equations are:

$$T_{1\%} = 0.753\, I_w + 7.611 \tag{7}$$

$$T_{5\%} = 0.775\, I_w + 4.040 \tag{8}$$

$$T_{10\%} = 0.782\, I_w + 0.289 \tag{9}$$

3. MAPPING OF THE PERCENTILE TEMPERATURES

Publications by the British Meteorological Office[13] and by the USAF Environmental Technical Applications Center[14] were used to derive warm and cold indices for 440 stations in the Southern Hemisphere. Indices were calculated for the warmest and coldest months for each location and were plotted on two AFGL Polar Equal-Area Maps of the Southern Hemisphere, one for the warm index and one for the cold index. The plot of each index included information on period of record (<5 years, <10 years, ≥10 years) and station altitude (≥1524 m or 5,000 ft, ≥3048 m, ≥4572 m) to aid in the analyses. Each percentile map was analyzed for the temperatures associated with the appropriate indices as indicated in Tables 3 and 4. The 1-, 5-, and 10-percent warm temperature maps are shown in Figures 4, 5, and 6, and the 1-, 5-, 10-, and 20-percent cold temperature maps are shown in Figures 7, 8, 9, and 10, respectively.

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13. Meteorological Office (1966) Tables of Temperature, Relative Humidity and Precipitation for the World, Part I-VII, Her Majesty's Stationery Office, *London.*

14. USAF Environmental Technical Application Center (1971) Worldwide Airfield Climatic Data, Vol. I-X; also published by U. S. Naval Weather Service entitled U. S. Naval Weather Service Worldwide Airfield Summaries.

Table 3. Index Corresponding to Temperature Equalled or Exceeded during 1-, 5-, and 10-Percent of the Warmest Month

Temperature ($^{o}C/^{o}F$)	Index Temperature (^{o}C)		
	1%	5%	10%
10/50	3.2	7.5	10.1
15/59	9.8	14.0	16.5
20/68	16.4	20.5	22.9
25/77	23.0	27.0	29.3
30/86	29.6	33.5	35.7
35/95	36.2	39.9	42.1
40/104	42.9	46.4	48.5
45/113	49.5	52.9	54.9
50/122	56.1	59.3	61.3

Table 4. Index Corresponding to Temperature Equalled or Colder during 1-, 5-, 10- and 20-Percent of the Coldest Month

Temperature ($^{o}C/^{o}F$)	Index Temperature (^{o}C)			
	1%	5%	10%	20%
10/50	12.7	9.8	7.9	5.9
5/41	7.9	4.9	3.2	1.2
0/32	3.1	0.0	-1.6	-3.4
-5/23	-1.8	-4.9	-6.3	-8.1
-10/14	-6.6	-9.8	-11.1	-12.7
-15/5	-11.4	-14.7	-15.8	-17.4
-20/-4	-16.2	-19.6	-20.6	-22.1

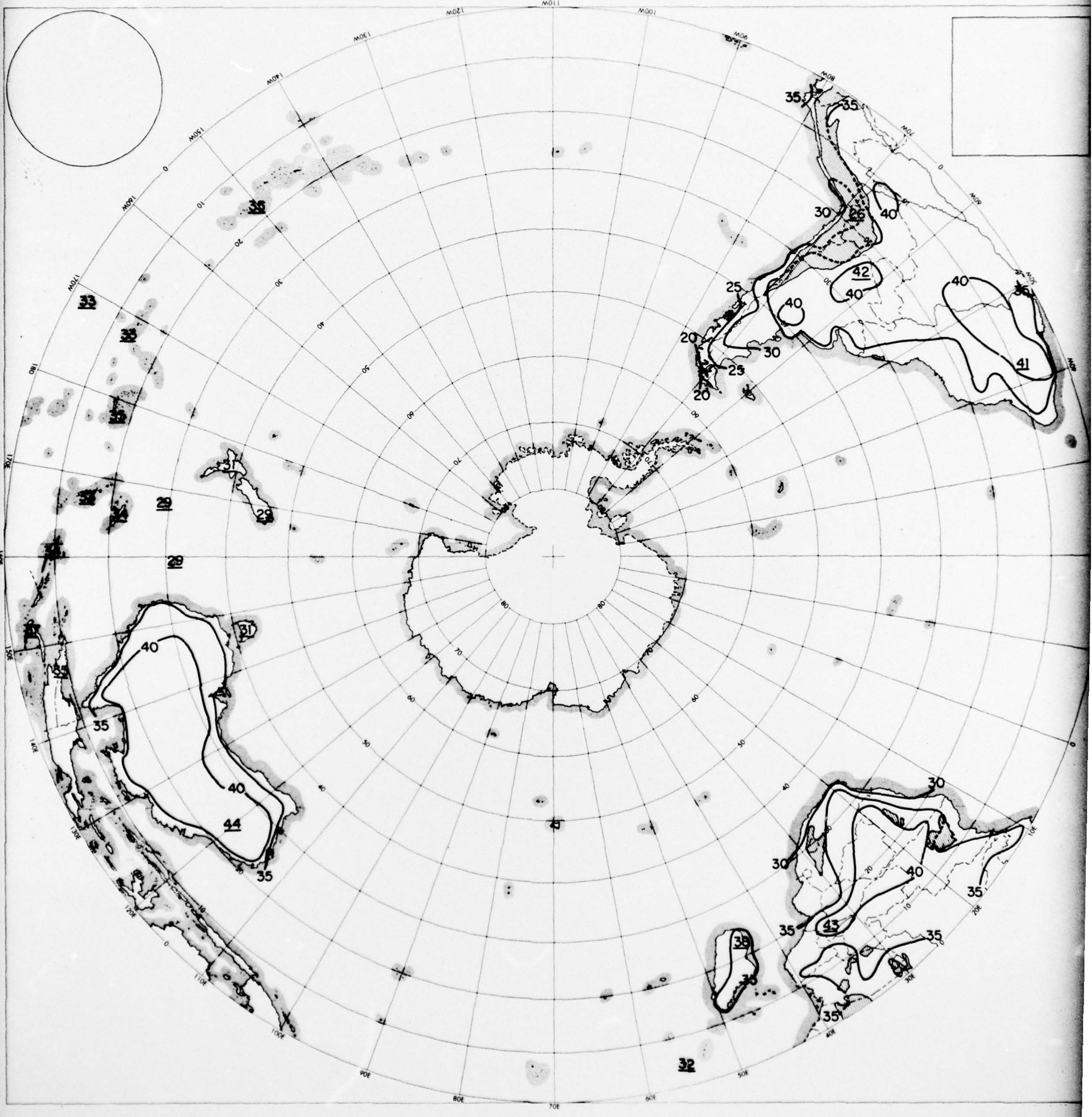


Figure 4. Temperature Equalled or Exceeded 1 Percent of the Time during the Warmest Month

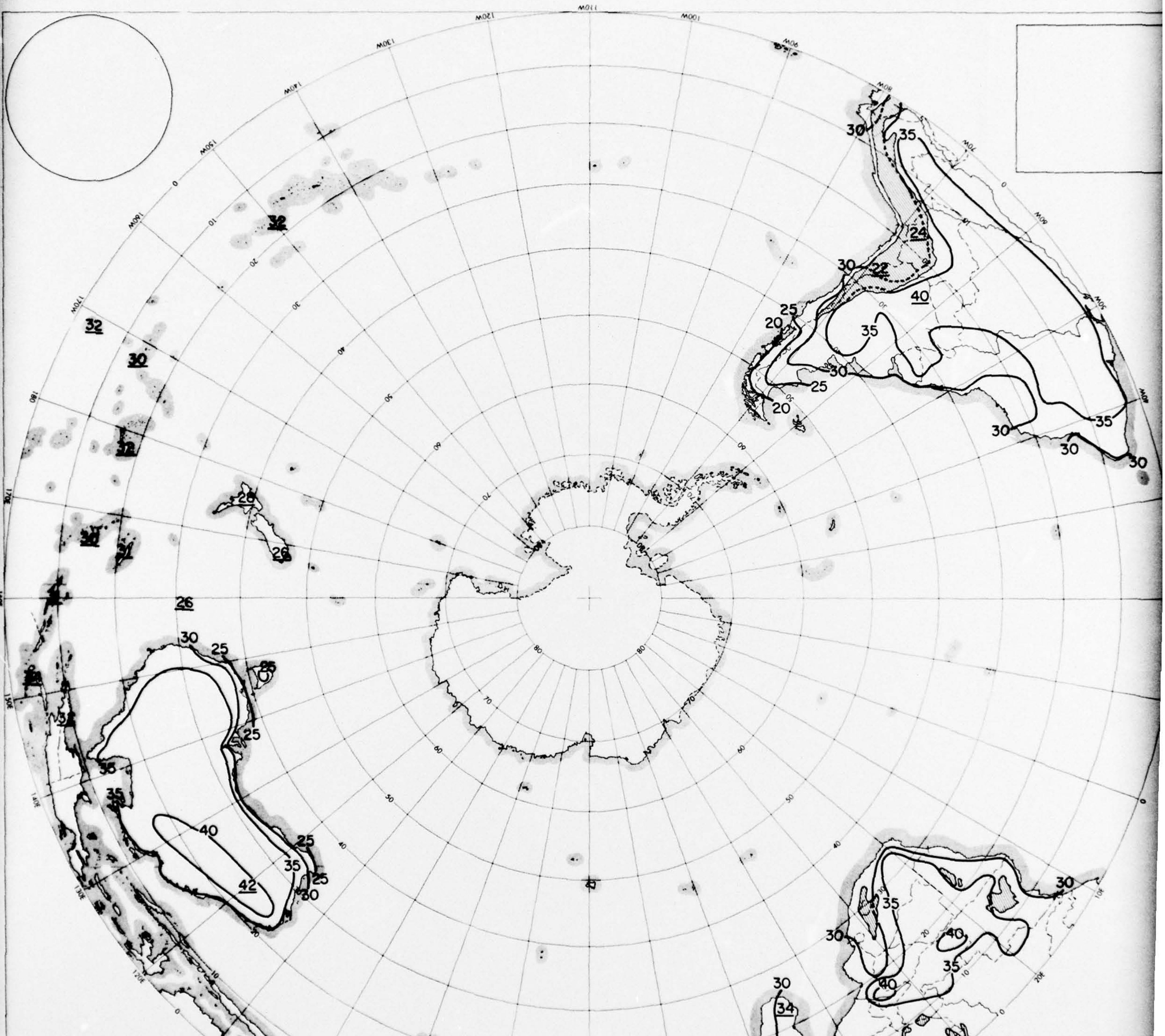


Figure 5. Temperature Equalled or Exceeded 5 Percent of the Time during the Warmest Month

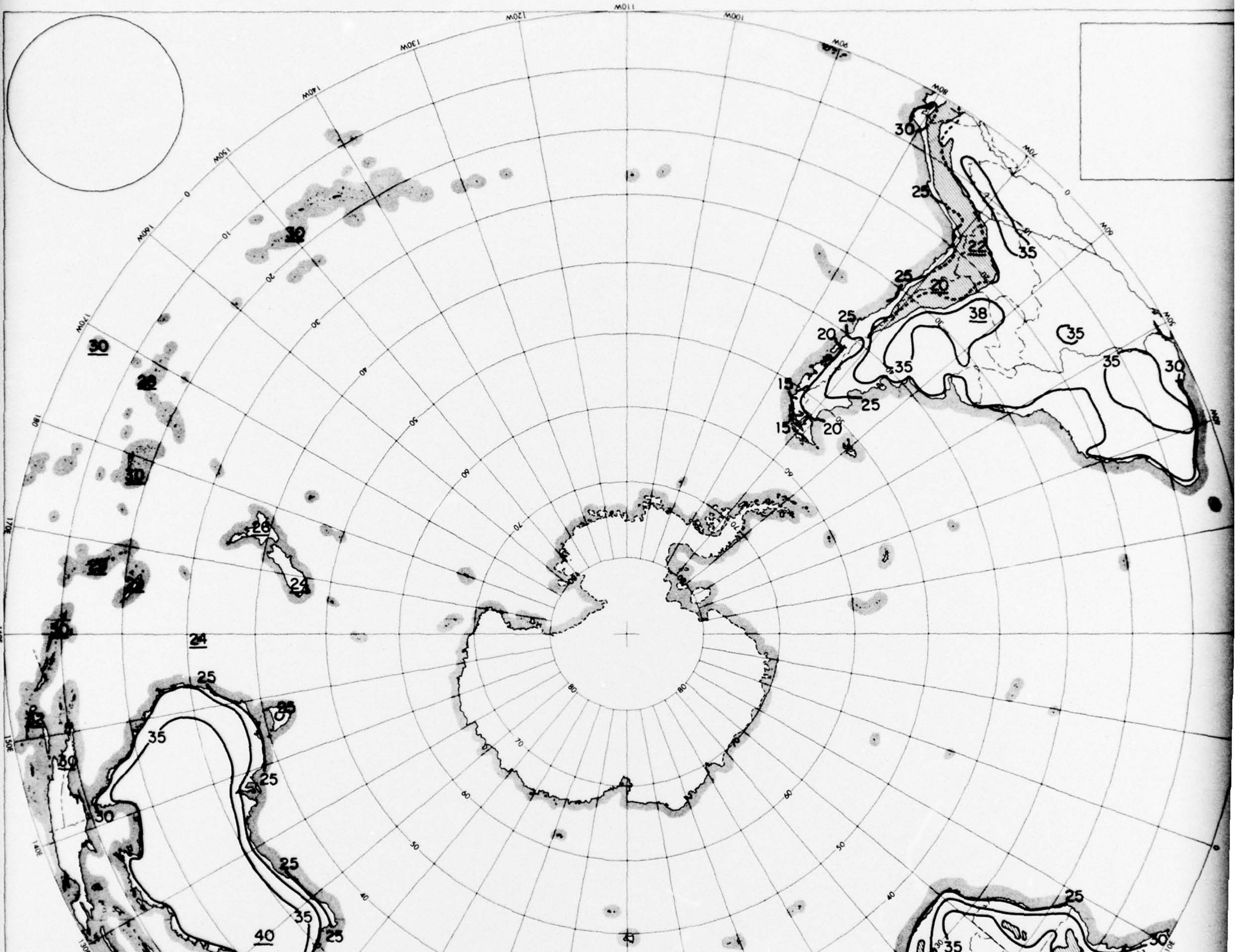


Figure 6. Temperature Equalled or Exceeded 10 Percent of the Time during the Warmest Month

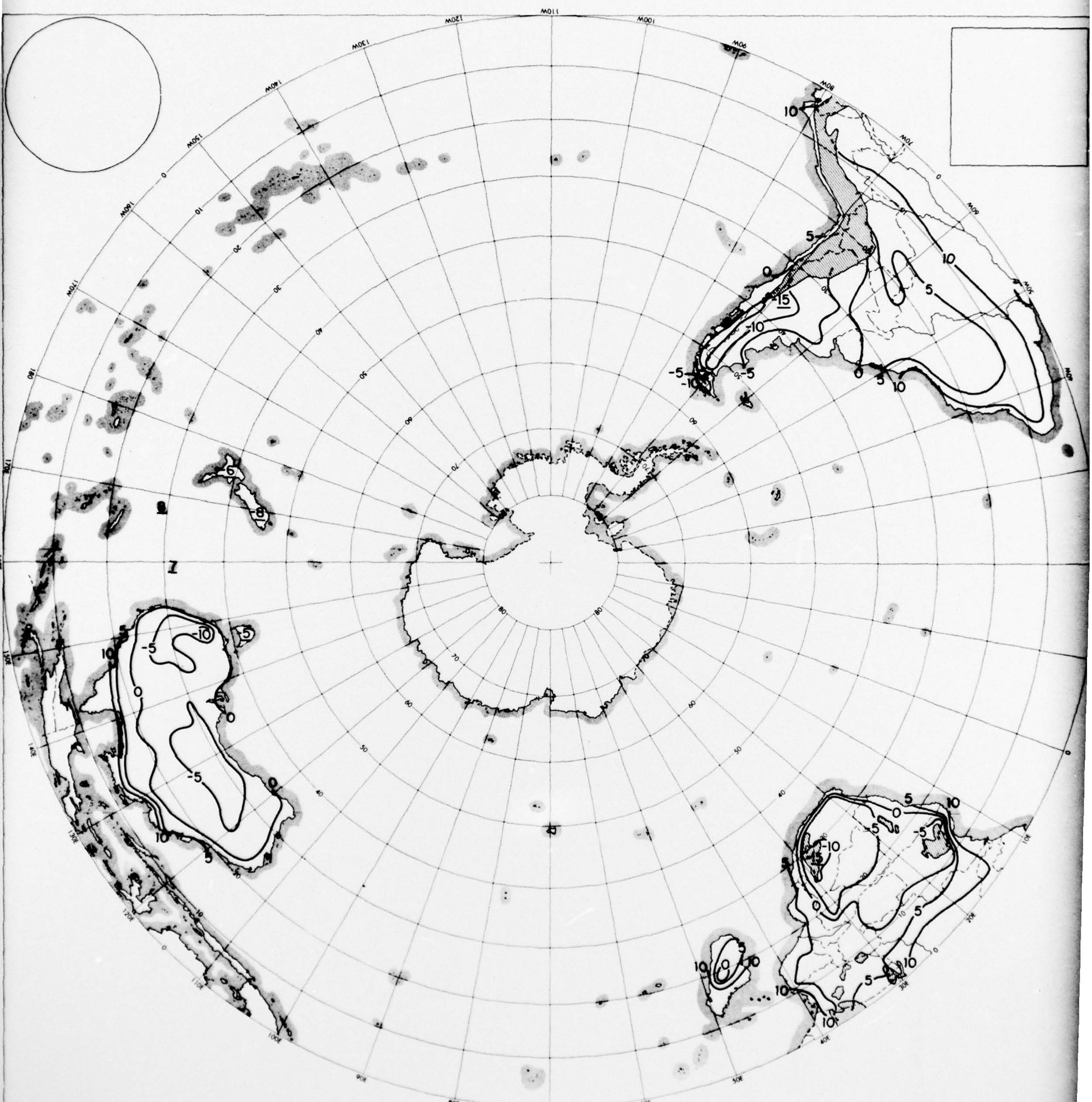
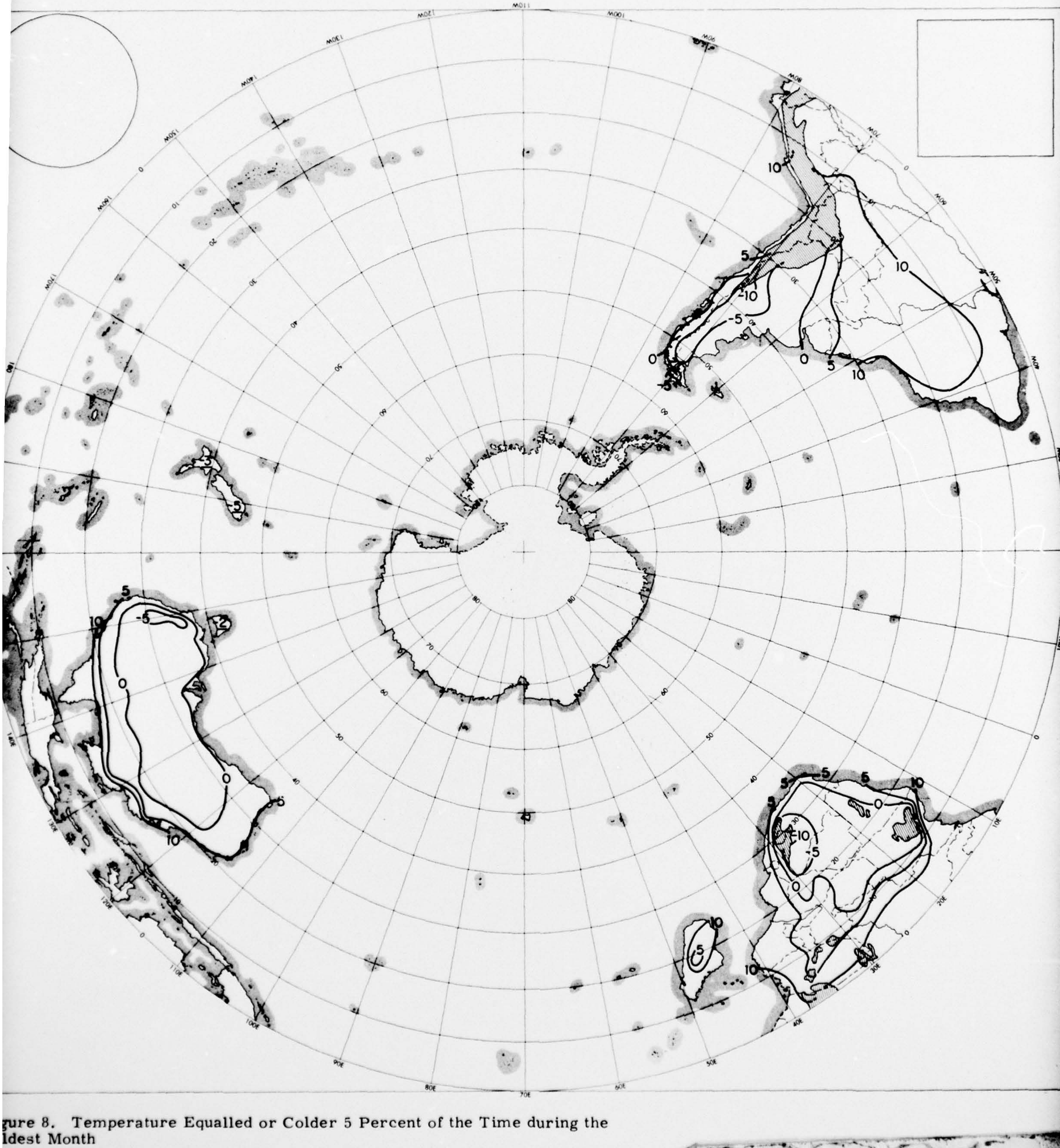


Figure 7. Temperature Equalled or Colder 1 Percent of the Time during the Coldest Month



gure 8. Temperature Equalled or Colder 5 Percent of the Time during the
ldest Month

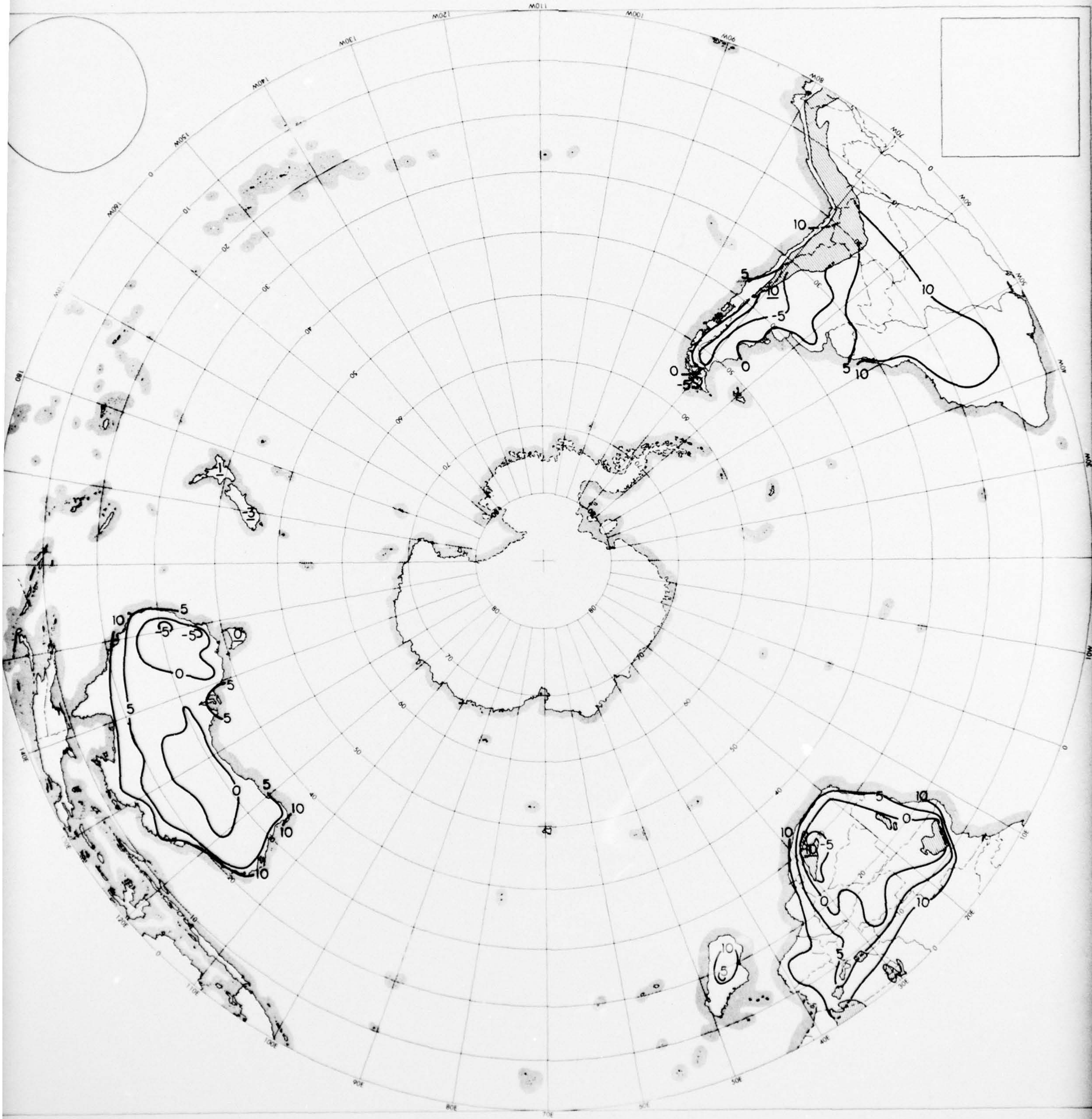


Figure 9. Temperature Equalled or Colder 10 Percent of the Time during the Coldest Month

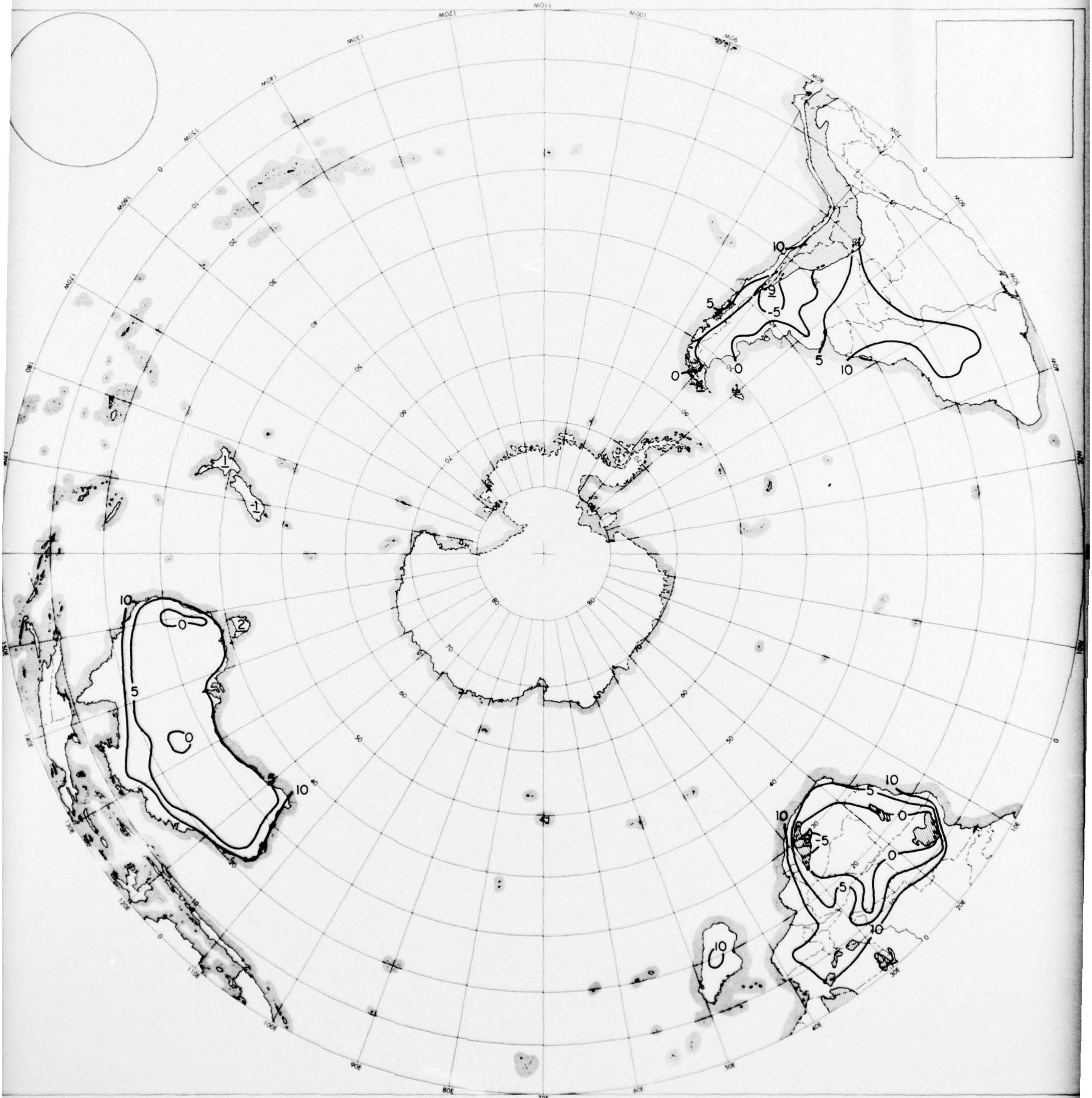


Figure 10. Temperature Equalled or Colder 20 Percent of the Time during the Coldest Month

One of the most difficult aspects of this analysis is the extreme temperature variations in mountainous areas. For example, strong gradients are common between nearby stations at different elevations, and extremes at mountain locations may not be representative. Consequently, elevations generally greater than 5,000 feet are hatched on the maps to alert the user to the presence of mountainous terrain and resulting large temperature variations with elevation and distance. Isotherms over these areas are dashed to indicate their uncertain validity. Dashed lines are truncated where there are insufficient data for analysis, and resumed where there are sufficient data. Designers or engineers requiring information on temperature distributions in mountainous regions should request special studies for specific locations.

Underlined values are used to indicate percentile temperatures at island locations. Most island locations have only one station. However, on islands with more than one station, the most extreme temperature is shown. Underlined values at inland locations are used to identify the warmest (coldest) temperature within an isotherm, where appropriate.

For convenience, isotherms were extended short distances over water areas, but this should not be considered an accurate analysis of temperatures over the water surface.

4. DISCUSSION OF THE TEMPERATURE MAPS

4.1 Warm Temperatures

The hottest part of the Southern Hemisphere is found in the interior of Australia. Most of this continent attains temperatures of 40 C (104 F) or greater 1 percent of the time during the hottest month (usually January). This is not as severe as the hottest parts of the Northern Hemisphere where large areas attain temperatures of 45 C (113 F) 1 percent of the time. The hottest location in Australia (where meteorological observations are taken) is Mundiwindi, which has a 1-percent temperature of 44 C (111 F) as shown in Figure 4.

Elsewhere in the Southern Hemisphere, a large part of Southern Africa has 1-percent temperatures of 40 C or more. The hottest location is Chisco, Mozambique which has a 1-percent temperature of 43 C (109 F) as shown in Figure 4. In South America several areas have 1-percent temperatures of 40 C. The hottest location, indicated in Figure 4, is Rivadavia, Argentina, which has a 1-percent temperature of 42 C (108 F).

4.2 Cold Temperatures

The greatest disparity in temperature extremes between the two hemispheres results from the relative mildness of the cold temperature extremes in the Southern Hemisphere. Of course, the coldest temperature ever recorded occurred in Antarctica, -88.3 C (-127 F), but this area is excluded from design consideration in MIL-STD-210B. The other continents in the Southern Hemisphere have 1-percent cold temperature extremes of about -15 C (5 F).

5. FURTHER CONSIDERATIONS

The temperatures on which this study is based where observed within standard meteorological instrument shelters. As a result, they approximate temperatures of the free air about 5 or 6 ft above the ground. The high temperatures described herein normally will be encountered during periods of strong sunshine and fairly light winds. Similarly, low temperatures generally will be encountered during nights with clear skies and little or no wind. The ground can attain temperatures from 15 to 30 C higher and 5 to 10 C lower than that of the free air, depending upon radiation, conduction, wind and turbulence.

Since the design philosophy for temperature extremes, as adopted for this report, is based on the probability of being exceeded during the warmest (coldest) month of the year, the risk or number of hours this temperature is encountered during any other month will be smaller than in the warmest (coldest) month. Also, the annual risk will be roughly one tenth of that shown for the warmest (coldest) month.

It should be noted that the warmest (coldest) month is not necessarily the same for each station. This fact, however, does not alter the desired concept of percentage of time (risk) of inoperability for design.

References

1. Tattelman, P., and Kantor, A.J. (1976) Atlas of Probabilities of Surface Temperature Extremes: Part I - Northern Hemisphere, AFGL-TR-76-0084.

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